OmniCAV: A Simulation and Modelling System that enables “CAVs for All”*

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Abstract— **OmniCAV is laying the foundations for the development of a comprehensive, robust and secure simulator, aimed at providing a certification tool for Connected Autonomous Vehicles (CAVs) that can be used by regulatory and accreditation bodies, insurers and manufacturers to accelerate the safe development of CAVs. To achieve this, OmniCAV is using highly detailed road maps, together with a powerful combination of traffic management, accident and CCTV data, to create a high-fidelity traffic and driving simulation environment to interact with the AV under test. Scenarios for testing are developed and randomised in a holistic way to avoid CAVs training to specific conditions. Critically, the simulator offers coverage of a representative element of the U.K. road network, through encompassing rural roads, peri-urban and urban roads to enable autonomy for all. The validity of the synthetic test environment compared to the real-world is of particular importance, and OmniCAV will be tested and refined through an iterative approach involving real-world comparisons and working in conjunction with a CAV testbed.**

I. INTRODUCTION

Over 1.25 million die due to on-road accidents worldwide every year [1] and it is suggested that 90% of these accidents occur due to driver error [2]. In the UK alone, there were over 1700 on-road fatalities, a figure which has remained the same for the last six years. Automated Driving Systems (ADS) (along with their connected technologies) have a potential to reducing the number of fatal accidents by either assisting the driver in the driving task or removing the driver from the driving task. Apart from the potential safety benefits of this technology, other potential benefits include lowered emissions [3], decreased drivers’ workload [4] and improved traffic throughput [5] etc. However, the safety benefit of ADS technologies can be realized only if the technology is introduced in a safe manner and used safely [6]. The complex nature of ADSs and their interaction with the environment makes their safety evaluation challenging [7], and requires novel test methods to be developed. While simulation is widely regarded in the Connected and Autonomous Vehicle (CAV) industry as a key component of the test methods for CAV evaluation [8], an understanding of the fidelity requirements for a simulation still evades the industry. The U.K. government is committed to ensuring safe and secure trial and deployment of connected and automated technologies, and making the U.K. as a global leader in CAV uptake with a key focus on simulation research and development.

In order to prove CAVs are safe, requires the creation of a legislative framework to prove AV technology is safe on the road, addressing widespread public concerns of CAV safety [9], and capturing the support of insurance companies and OEMs alike. Today's vehicle testing infrastructure, relies on physical testing which cannot, cost and time efficiently and with due regard for public safety, deliver the number of road miles [10], coverage of test cases and repeatability required for AV software certification. Industry and government end-users are looking to simulation to fill this gap as part of a systematic, stage-gated testing regime integrated with CAV testbeds.

To meet these challenges, the OmniCAV project was initiated which engages end-users in its consortium to help navigate these complex market dynamics, and is focused on addressing key gaps in the current state-of-the-art to deliver a simulation platform

II. METHODOLOGY

OmniCAV addresses the need for a holistic simulation system through delivering a Proof-of Concept (PoC) of an integrated virtual and physical testing regime, covering rural and urban roads, and considering needs of key end-users. By 2021 the project will deliver a PoC testing regime, together with a viable virtual and physical platform for AV testing validated against end-user need based on the following four stages (Fig. 1):

A. Stage 1: Data collection

Collecting environment and agent data to produce a high fidelity "digital twin" of a combined rural/urban road loop in Oxfordshire in the U.K. (No simulation today covers rural as well as urban roads, despite these representing 93% of the U.K. and posing specific challenges (e.g. narrow lanes, lack of data, inadequate GPS coverage)). Extent and features of the test bed are shown in Fig. 2.

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B. Stage 2: Scenario generation

Combining three hazard identification methodologies to develop a scenario library, scenario definition language and evaluation plan: addresses state-of-the-art gap on scenario generation.

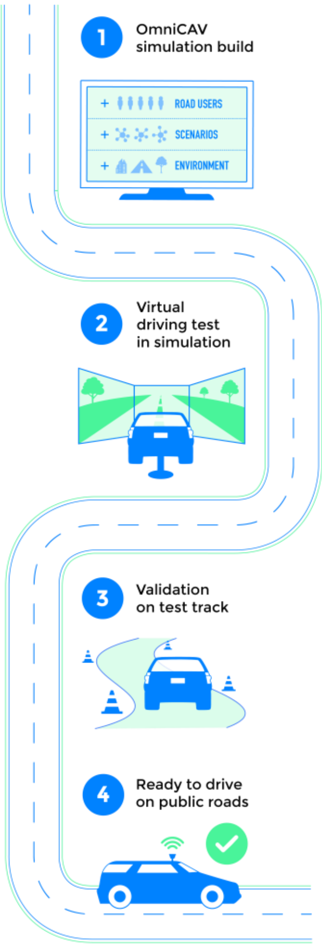

Figure 1: Functional structure of the OmniCAV project

C. Stage 3: Novel Comprehensive simulation platform

Integrating these into a simulation platform, encompassing a traffic simulator to control wide-view traffic, a driving simulator for close-in interactions and agent models: address state-of-the-art gap on modelling, simulation levels, and certification

D. Stage 4: Testing strategy

Validating simulated tests against results in a physical environment and completion of a proof-of-concept testing regime involving simulation, testing ground and on-road: addresses the objective of building confidence in AV decision making and accelerating AV development.

III. Architecture and Requirements

In order to support a PoC as well as position for future (post project) development, it is critical to define an architecture that is modular and employs, where available, standard interfaces between core components. Given the complexity, immaturity and in some cases, disparity of the current CAV eco-system between nations and amongst manufacturers, this is not straightforward. This is further compounded by having no current common interface across sensors, requiring development to be based around specific supplier products and future modifications for every new sensor to be simulated. The OmniCAV high-level architecture is shown in Fig. 3.

This simulation architecture is designed to be used to validate the synthetic environment against the real world to show how viable it is as a digital twin, so, demonstrating that simulation could be used as a key tool for providing CAV test evidence to support a CAV safety case. It is not expected that simulation, by itself, will provide all the evidence for CAV accreditation, but instead will be a key aspect of a mixed synthetic/on road test programme. Simulation will give highly repeatable, controlled, testing, at potentially faster than real time and critically, will be able to put the CAV in situations that would be dangerous or difficult to construct in the real world.

Further, through closed loop testing of the CAV and understanding of the CAV internal architecture, it is possible to identify potential stress test cases for the CAV. It is one of the aims of this project to be able to demonstrate how scenario parameter selection can be automated to determine the worst case combination for the CAV.

IV. Data Collection

The OmniCAV Oxfordshire route comprises a loop of approximately 32 kilometers, taking in the town of Abingdon, the western fringes of the City of Oxford and various villages in the countryside. The route includes villages, farms, narrow roads and many trees and bushes as well as built-up urban environments and complex, busy road junctions.

A 3D model of the route was needed for the project, and this required several different data sources to complete it. High accuracy control surveys were carried out to capture ground control information along the route; a road-vehicle-mounted mobile mapping system with multiple sensors was used to drive the route and airborne surveys were used to fill in the detail away from the immediate environs of the road. Ordnance Survey took on the role of creating the geospatial data model, using input from Korec and GeoXphere, who supplied the raw data from mobile mapping and aerial survey systems, respectively.

A Trimble MX9 mobile mapping system was used to capture both imagery and lidar data of the route. The Oxfordshire loop was driven twice in the daytime (clockwise and anticlockwise) and twice in the nighttime (clockwise and anticlockwise) to produce multiple views of the same route. Lidar point clouds from the different passes were combined

Fig. 2: Test bed location

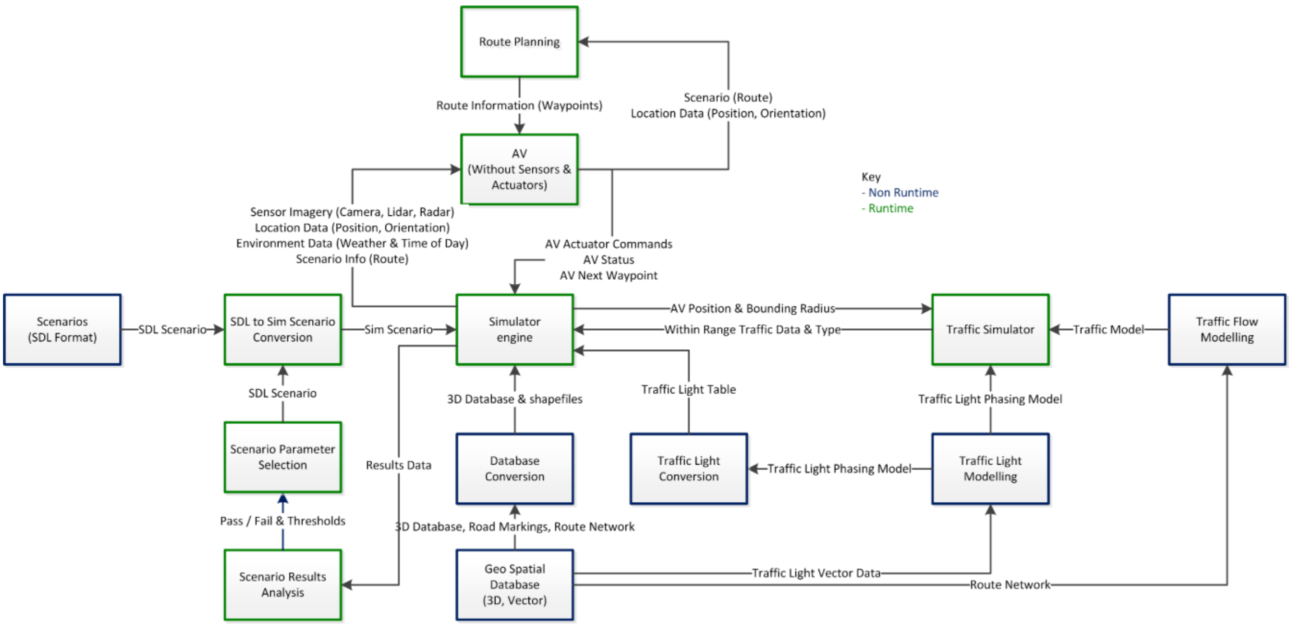

Fig. 3: OmniCAV simulation schematic diagram

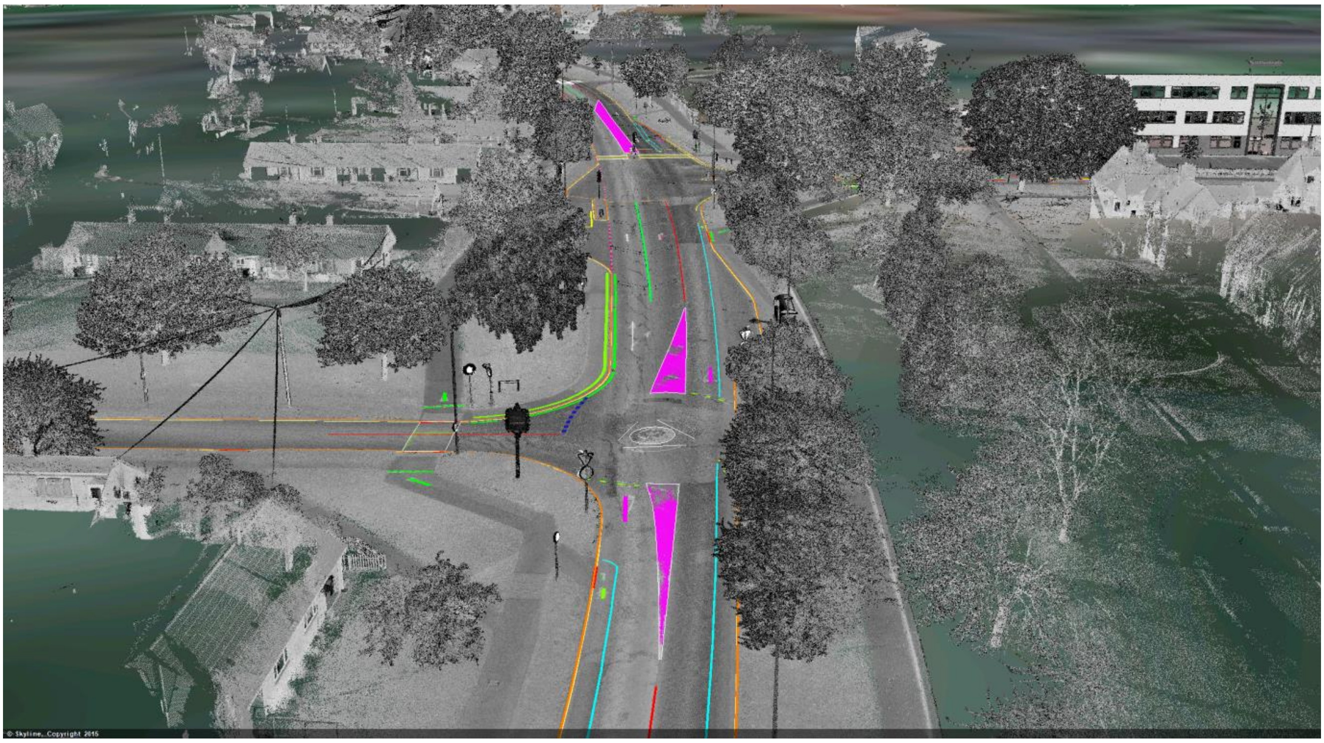

Fig. 4: Extracting information from a data point cloud

and each point was assigned a colour from the daytime imagery. Processing large volumes of this type of data is extremely time-consuming, so to mitigate against this the point clouds were thinned to provide a dataset which was dense enough to model the surface of the road in sufficient detail but not too dense to make the 3D model too unwieldy (Fig. 4).

Aerial imagery was collected using the XCAM, an oblique camera system which is flown in an advancing circular path rather than the traditional series of straight lines. This enables multiple views of every point on the ground and allows objects such as buildings to be viewed from many different angles.

To build the 3D models used in the simulation, many different skills were employed, including the capture of kerbs and road edges, the collection of the positions of all the street furniture and vegetation lining the road, the crafting of 3D objects for all the features encountered on the route and the creation of terrain surfaces. The data required for the simulation was in many ways quite different to typical geospatial data, for example, it was originally thought that a “traffic light” could be treated as a single object that could simply be copied and pasted into the model at the appropriate positions. However, traffic lights come in many different configurations (for example, red-amber-green, red-amber-green_right_arrow, red- amber- green_left_arrow, red/amber/ green_straight_arrow, and many more), each of which requires its own model. The nature of the road itself was also complex. Upright, uniform and crisp kerb edges at the side of the road are not common in rural areas. Instead the edges of the road are often obscured by vegetation, mud or leaves and it is a challenge to define a linear representation of the road edge, as was needed in the model. These had to be modelled as a “closest possible” representation of the real-world, with some acceptance that this would never be entirely accurate.

In order to be able to deliver a set of data models that would satisfy the requirements of the simulator in the timescales required, a set of representative “areas of interest” were chosen around the route based on the requirements for specific scenarios. The areas of interest were captured to the full data specification, while the areas between were captured to a lower level of accuracy. These areas of lower accuracy will be helpful in determining if certain aspects of simulation can be adequately completed using reduced detail.

V. Scenario Generation

It is suggested that in order to statistically prove autonomous vehicles are safer than human-driven vehicles, they need to be driven for over 11 billion miles [11]. However, an alternate school of thought exits which argues that just driving miles is not beneficial in evaluating safety of the AVs and ADSs, as there is little to be gained from driving 11 billion miles on sunny deserted roads. To this end, Hazard Based Testing (HBT) has been proposed which focusses on identifying *“how a system fails”* as compared to *“how a system works”* [12]. Based on the HBT concept, OmniCAV uses a novel hybrid approach to create test scenarios focusing on identifying failures.

First, OmniCAV uses accident database analysis to identify accident hotspots and parameters which contribute to causation of accidents (with varying levels of severity). Stats19 and RAIDS accident databases, which are both UK based databases are used for this purpose. Second, anonymized vehicle insurance claim records collected by one of the partners of OmniCAV (Admiral), is used to identify trends in the situations that lead to insurance claims. Third, a Systems Theoretic Process Analysis (STPA) [13], which is a systems based method safety analysis method to identify failures was used as a foundation and its extension [14], was used to create test scenarios. STPA was done for both the Autonomous Control System and the Brake-by-Wire actuation system. Using the three methods of scenario generation, a scenario library is being created which is aligned with U.K.'s National CAV Test scenario Database, part of the Midlands Future Mobility [15]. STPA of higher abstraction of the ACS revealed 1190 requirements and over 3000 scenarios. STPA of BBW revealed 3736 requirements and over 5000 scenarios.

Another consideration for test scenario definition is the creation of a common language for defining test scenarios such that it meets the needs of the diverse stakeholders (e.g. system engineers, safety analysis, simulation engineers, regulators etc.) using the test scenarios [12]. OmniCAV has created a two abstraction level Scenario Definition Language (SDL) – SDL level 1 and SDL level 2. SDL level 1 uses a high level abstraction language (to be used by regulators, safety analyst etc.), while SDL level 2 is ingested by the simulation engine to instantiate the test scenario in the simulation world. A mapping between SDL level 1 and level 2 enables the end user to change the level of abstraction in the scenario as per the usage.

VI. Simulator Development

Building upon the range of expertise across the consortium, a PoC simulator is being assembled that brings together CAV simulation, using, where possible, realistic CAV to simulator interfaces (such as GMSL and CAN) through which to stimulate the heart of the CAV to test its detection and decision making algorithms under normal and edge case conditions. To ensure that the simulation environment is adequately rich, it uses accurately mapped real-world data, giving terrain, road, vegetation and street furniture detail, and links with a calibrated traffic model of the corresponding real-world route to provide representative dynamic actors in the scene. The simulator build programme has been phased to allow buildup of functionality and complexity, with the following 3 main stages identified:

A. *Phase 1: Sensor validation*

In this phase, a synthetic environment will be set up to allow simulation of a simple off-road scenario without dynamic actors or traffic lights. This will allow initial testing of the simulation pipeline and comparison between recorded real-world sensor data and that generated by the simulator.

B. *Phase 2: Traffic validation*

This phase adds the simulation of the dynamic actors within the synthetic environment, starting with vehicles (cars, vans and lorries) and moving to include cyclists and pedestrians within an on-road setting. The actors will be characterized (type, movement and flow) based on previously recorded data for this real-world location. Traffic light sequencing will be modelled within the simulation using staging information provided by the council and the database will be validated against the real world for accuracy. This simulation phase will provide more challenging testing of the simulation pipeline, including performance testing and allow initial assessment of the CAV detection and decision making algorithms as stimulated within the synthetic environment.

C. *Phase 3: Full functionality*

This is the final integration phase where the full functionality simulator will be ready for validation testing to confirm its credibility as a digital twin of the real world and initial proof of capability to use this synthetic environment as a valid test bed for CAV accreditation. In this phase, a high level scenario, described in a domain specific scenario definition language, will be used to define what needs to be enacted in the simulator, in such a way that their subsequent interpretation by the simulation environment will allow sufficient variability (to avoid CAV learning each test scenario) but being adequately prescriptive to allow testing of the required conditions.

VII. Testing Proof-of-Concept

OmniCAV project has two types of Proof-of-Concept (PoC) testing. First, is the testing of the ADS and second is the testing of the OmniCAV simulation platform to evaluate its ability to represent the real-world environment. While the former requires us to test first in the simulation environment and then in the real-world environment, the later calls for a reverse approach. For testing the simulation environment, we first gather data from driving the ADS in the real-world and use the gathered data to replay the scenarios in simulation to compare the results.

Once the simulator is validated and representative of the physical world, the OmniCAV project will demonstrate a PoC of how the Autonomous Driving System could be validated using both physical and virtual testing. The project will be using the Arrival Autonomous Driving System (ADS) fitted to the Arrival Van, a light commercial vehicle designed from the ground up to be capable of being driven autonomously.

Fig. 5: Arrival van

Fig. 6: Example of the OmniCAV photo realistic simulation environment

Prior to real-world deployment the Arrival ADS will pass through a series of gateway tests, starting in simulation and only progressing into the physical (controlled) and physical (public road) tests once its safety has been proven at the previous gateway. The PoC will use the intensive validation capability of the simulator in scenarios specifically generated based on the vehicle architecture using the STPA of the Arrival ADS done as part of the project, accident data analysis and insurance claims data analysis.

VIII. Discussion

This paper has illustrated the programme being undertaken by the OmniCAV consortium to develop and pilot an integrated simulation and testing environment for CAVs with a focus on the production of a system, in early 2021, that will be able to handle the majority of the complex road types found in the U.K. The output of the project will be in need of escalation through increasingly high TRL (Technology Readiness Levels) in the coming years but addresses a clear need. The global driving simulation market is forecast to be worth c£10bn by the completion of the project [16], however, this is likely to expand as markets for CAV testing evolve. (Indeed more recent estimates with reference to the overall CAV market it enables, have forecast £907bn by 2035 globally, £28bn in the U.K. [17], with CAV technologies comprising £63bn globally, £2.7bn in the U.K., more than quadrupling over 2020-2035). With 50% of development costs estimated as being spent on verification and validation of complex autonomous systems, this suggests a global market of CAV technology testing of up to £30bn p.a. by 2035. Triangulating this against the average spend by OEMs on warranty costs, averaging at c4% of revenues, or £36bn by 2035 based on CAV sales of £907bn.

The potential marketplace for solutions of this kind is clearly vast and OmniCAV is working with the consortium end-users and broader stakeholders in the consortium to validate this estimation. Growing international competition from VC-backed simulation specialists (e.g. RightHook) and technology giants (Nvidia) validates this opportunity whilst emphasising the imperative for prompt action and it is hoped that OmniCAV can expand in both its quality and quantity (viz. scenarios and realms of applicability) in the years ahead.

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